GENERALIZED SCATTERING MATRICES FOR UNIT CELL CHARACTERIZATION OF GRID AMPLIFIERS AND DEVICE DE-EMBEDDING†

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I. Introduction

Amplifying grid arrays [1], consisting of periodic unit cells loaded with active devices such as HEMTs, are currently being developed for high frequency quasi-optical use. Motivation for their development includes the inherent advantages of an approach that employs spatial power combining and spatial amplification. Thus losses between multistage amplifiers is virtually eliminated. Also due to the spatial combining, the phase of the array is determined by the phase of the incident wave which is then amplified by the planar circuit. This eliminates the need for complex phase shifters and the associated lines for independent element control. Other advantages include the existence of graceful degradation when failures occur.

Future NASA space probes are investigating usc of these higher frequency low power transmitters due to their light weight and potential for increased reliability. In addition theses planar arrays could be fabricated monolithically and therefore are potentially more economical than hybrid circuits. Typical application for both space and ground uses would include JPL/NASA Deep Space Network(DSN) general purpose communications, radar, and radio science experiments such as gravity wave detection.

II. Unit Cell Characterization

Typically in the past the unit cell of these planar arrays has been analyzed using quasi-static transmission line approaches. This approach is used due to its simplicity and the easy addition of the port locations required by the active devices. The benefit of a grid amplifier design at high frequency is limited by this approach. Based on more conventional periodic array analysis, the method described here extended the generalized scattering matrix approach [2] to include the port locations of the device. This allows accurate inclusion of the effects of the mutual coupling between elements, the presence of bias lines, ground planes, and supcrstratcs/substrates. In addition this numerically generated scattering matrix can be combined with the conventional scattering matrix of the device to form a composite matrix of a grid amplifier. Thus conventional amplifier design approaches can now be applied to planar grid amplifier design. For example, addition of a polarizer for tuning requires the inclusion of the scattering matrix for this structure.

Similar approaches to this method have been applied to multilayered printed structures by other authors [3, 4]. In contrast to other approaches the Y or Z parameters arc not calculated. This method also recognizes the additional 4 ports created by two polarizations of the scattered and reflected fields for normal

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incidence on an infinite array. In addition the port(s) defined at (he device or load location is within the plane of the array, and therefore not terminated in a microstrip line with a known characteristic impedance. Such a unit cc1l for a onc port dipole is shown in Figure 1. By modifying the generalized scattering matrix for a periodic array, the additional one or more ports at the device location arc accounted for.

111. Waveguide Simulator: Device De-embedding

In order to verify the generalized scattering matrix that is numerically generated and to demonstrate a novel method of device de-embedding, a waveguide simulator has been built. This simulator models a periodic array by inclusion of a single element as shown in Fig. 1. Fig. 2 shows the complete test setup which includes two orthomodes that allow both orthogonal polarizations of the reflected and transmitted waves in the square waveguide to be measured, Since the square waveguide of the orthomode junctions supports two fundamental modes, conventional calibration techniques cannot remove their presence in the measurement setup. Therefore, the scattering matı ices of the orthomode junctions arc determined experimentally.

The generalized scattering matrix of the unit cell supported by a dielectric of $\varepsilon_r = 2.2$ is calculated numerically to include the port where a chip resistor is placed as the Device Under Test (D. U.T.). Fig. 1 shows the simplistic case where only onc polarization is incident on the dipole antenna loaded by the D.U.T. Since the generalized scattering matrix of the dipole and orthomodes are known, the S parameters of the D.U.T. can be determined by measuring the S parameters at the external ports of the orthomode junctions. Figs. 3 and 4 show results for de-embedded chip resistor values of51 and 120 ohms. These figures demonstrate the usefulness oft he numerical 1 y generated scattering matrix of the planar unit cell. The phase corresponding to Figs. 3 and 4 is not shown, but was found to be less than 15 degrees over the range of measurements.These measurements involved the use of a 5 port scattering matrix for the unit cell. The approach is currently being applied to measurment of the two port scattering matrix of a HEMT (differential pair using a 6 prot scattering matrix for the unit cell.

IV. References

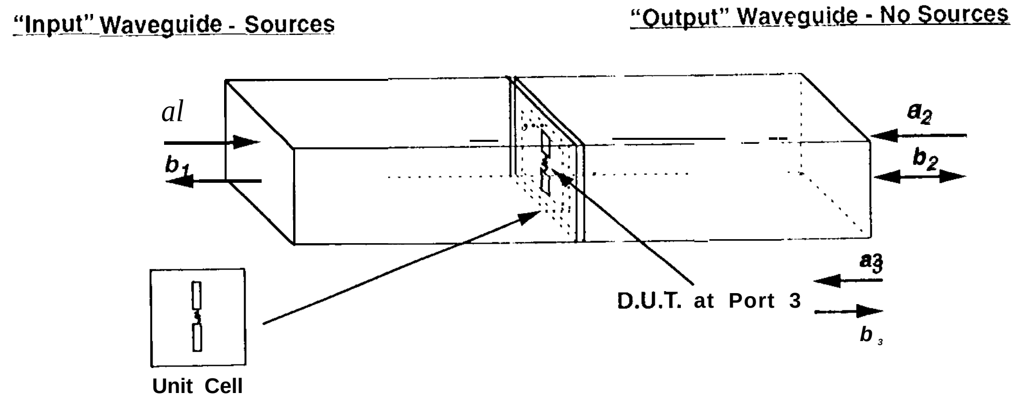
[1] M. Kim, J. J. Rosenberg, R. Peter Smith, R. M. Weikle, Ii, J. B. Hacker, M. P. DeLisio anti D. B. Rutledge, "A grid amplifier," *IEEE Microwave and Guided Wave Letters,* vol. 1, no. 11, pp. 322-324, Nov. 1991.

[2] R. C. hall, R. Mittra and K. M. Mitzner, "Analysis of multilayered periodic structures using generalized scattering matrix theory," *IEEE Transactions on Antennas and Propagation, vol. 36,* no. *4,* pp. *511-5 17,* April 1988.

[3] N K. Das and D. M. Pozar, "Multiport scattering analysis of general multilayered printed antennas fed by multiple feed ports: part I - theory," *IEEE Transactions on Antennas and Propagation*, vol. *40,* no. *5,* pp. 469-481, May 1992.

[4] M. Guglielmi anti A. A. Oliner, "Multimode network description of a planar periodic metal-strip grating at a dielectric interface - part *1:* rigorous network formula tions," *IEEE Tran sactions on Microwave Theory and Techniques, vol. 37, no.* 3, March 1989.

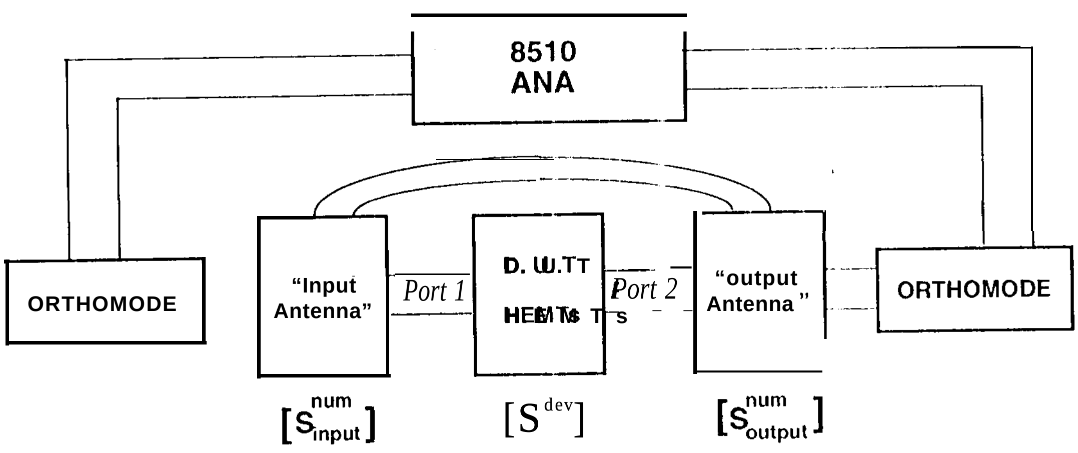
FIG. 1. WAVEGUIDE METHOD OF ONE PORTS PARAMETER DE-EMBEDDING



$$S_{11\,D.U.T} = \frac{b_2 - a_1 S_{21}}{a_1 S_{23} S_{31} + b_2 S_{33} - a_1 S_{21} S_{33}} \quad \text{OR} \quad S_{11\,D.U.T} = \frac{b_1 - a_1 S_{11}}{a_1 S_{13} S_{31} + b_1 S_{33} - a_1 S_{11} S_{33}}$$

S21, S23, . . . ***generated numerically!***

FIG. 2. IMPLEMENTATION OF WAVEGUIDE METHOD FOR TWO PORT S PARAMETER DE-EMBEDDING



- MODEL BASED ON GENERALIZED S MATRICES ACTUALLY *DE-EMBEDS* $[S^{dev}]$

FIG. 3. MEASURED LOAD MAGNITUDE, DIPOLE LOADED WITH 51 OHM CHIP RESISTOR

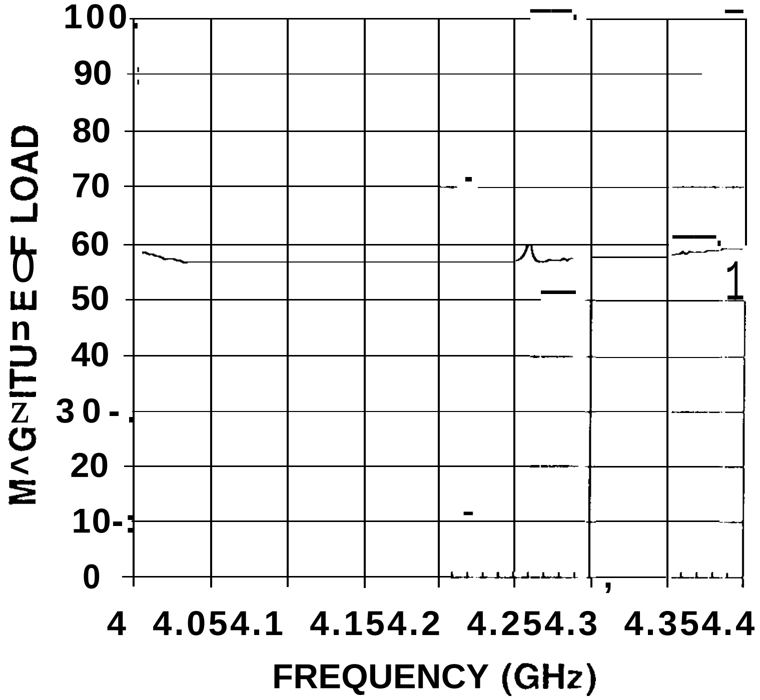


FIG. 4. MEASURED LOAD MAGNITUDE, DIPOLE LOADED WITH 120 OHM CHIP RESISTOR